NASA-CR-66385

RELIABILITY AND QUALITY ASSURANCE PLAN FOR THE DESIGN, DEVELOPMENT, AND PRODUCTION OF A SPACE PROBE ALTIMETER

Final Technical Report
Volume 3 of ~~3~~

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Prepared under Contract ~~No.~~ NAS 1-5954 by
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for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOREWORD

This is volume three of a three-volume set of documents comprising the final report of a study to define the design of a space probe altimeter. The documents of this set include the following:

1. Design
    - a. Detailed Conceptual Design
    - b. Drawings
    - c. Growth Potential
2. Developmental Plan
    - a. Project Planning Network
    - b. Manufacturing Plan
    - c. Environmental Tests Program Plan
    - d. Flight Test Qualification Plan
    - e. Facilities Plan
    - f. Project Funding Plan
3. Reliability and Quality Assurance Plan
    - a. Reliability and Quality Assurance
    - b. Predicated Effects of Sterilization

This study was conducted by Texas Instruments Incorporated Apparatus Division for the National Aeronautics and Space Administration, Langley Research Center, Langley Station, Hampton, Virginia, under Contract Number NAS 1-5954, from March 1966 to November 1966.

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RELIABILITY AND QUALITY ASSURANCE PLAN FOR THE DESIGN, DEVELOPMENT AND PRODUCTION OF A SPACE PROBE ALTIMETER

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SUMMARY

Texas Instruments Incorporated has prepared a detailed conceptual design for an all solid-state space probe radar altimeter. This report provides a preliminary reliability and quality assurance plan. Other NASA programs in progress at Texas Instruments are referenced as existing compatible capabilities.

A current reliability estimate of the design is included. The probability of successful operation of the altimeter described in this report, during a one-half hour letdown to landing on the planet Mars, is estimated to be 0.999982.

INTRODUCTION

Texas Instruments Incorporated has been engaged by the National Aeronautics and Space Administration, Langley Research Center (NASA, LRC) to perform a study to define the design of a space probe altimeter. This plan has been prepared in response to Paragraph 6.4.2 of Statement of Work for Study to Define the Design of a Space Probe Altimeter, L-6050, dated 19 August 1965, and prepared by Langley Research Center, Langley Station, Hampton, Virginia. The plan presents a current reliability analysis and provides for control of reliability and quality assurance during the following phases.

a. Design
b. Production (10 Units)
c. Qualification Test Program
d. Flight Test Program

This plan is developed from the following NASA publications:

Reliability Publication NPC 250-1, July 1963 edition
Quality Publication NPC 200-2, April 1962 edition.

Under the requirements of NPC 250-1, Paragraph 2.2, this plan is considered to be a preliminary plan. Possible revisions are anticipated before the contractual or final plan is evolved. During one of these revisions, the plan will be divided into separate reliability and quality assurance plans to conform with Texas Instruments standard operating procedures and divisions of authority as delineated in Appendix B.

Program Management

Texas Instruments has a clearly identified group within its organization which is responsible to management for the execution of the reliability program. Although the accomplishment of many of the planned reliability tasks are not the line responsibility of the cognizant reliability engineer, and will be performed by other elements within the company, he will monitor these tasks and ensure that all are accomplished effectively. He will be delegated full authority to discharge this responsibility, will have direct unimpeded access to top management, and will devote full time to this effort.

Management controls, such as PERT, GANTT, and milestone charts, will be included in later revisions after NASA's requirements have been made known.

Reliability Requirements

The reliability requirements are not specified as a failure rate, MTBF, or probability of mission success. A probability of mission success, including 30 minutes of active operation during the entry of the Martian atmosphere, was arbitrarily assigned to be at least 0.9999, with 0.99999 considered an achievable goal.

The Work Statement, L-6050, does specify the general mission, but it does not provide system environmental estimates for the mission. Sterilization requirements are specified. Mission and other environmental requirements were assumed to be equivalent to that of Mariner Mars 1969, up to landing approach, as set forth in Jet Propulsion Laboratory (JPL) document entitled "Preliminary Issue 2D0800 Project Document 92 Mariner Mars 1969 Spacecraft System Environmental Estimates," dated 15 July 1966.

It is assumed that the descent to Mars will be approximately equivalent to the launch stresses with the exception of temperature. The environmental stresses described in following paragraphs, that contain asterisks below, were assumed by Texas Instruments. Five explicit environments are anticipated during the life of a system. These are:

a. Sterilization (non-operating)
b. *Prelaunch spacecraft maintenance and handling (both operating and non-operating)
c. *Launch (non-operating)
d. *Free flight deep space (non-operating)
e. *Mars approach with entry of atmosphere and deceleration (operating).

Sterilization (non-operating). —The components shall be capable of satisfactory operation after complying with sterilization requirements as set forth in Jet Propulsion Laboratory document entitled "Environmental Specification Voyager Capsule Flight Equipment Type Approval & Flight Acceptance Test Procedures for the Heat Sterilization & Ethylene Oxide Decontamination Environments." The maximum temperature specified therein is 135°C with the equipment non-operating.

Prelaunch spacecraft maintenance and handling (both operating and non-operating). —It is assumed that each system will be hand carried during all transportation. Vibration during check-out and installation should not be significant.

Shock experienced by assemblies during handling usually occurs when an assembly, without protective packaging, is dropped on a work bench or table. These drops can occur from various positions. The position that delivers the maximum shock is when one point of the assembly is placed in contact with the table and the assembly is released from a 45-degree inclination.

It is expected that the temperature environment for the spacecraft equipment during ground operations will be well controlled. Severe temperatures or transients are unlikely provided proper precautions are taken. An estimate of the environment during these operations is temperatures ranging from 4° to 38°C with transients of 5.6°C per hour or less. The equipment may be operating or non-operating during exposure to this environment.

Launch (non-operating). —The equipment will not be operating and will be protected from external radiation by the sterilization canister. Significant environmental parameters will be:

a. Low frequency sine vibration—1.0 g peak axially, 0.7 g peak laterally, 2.5-160 Hz, short duration.
b. Random vibration—0.028 g^2/Hz, flat 350 to 750 Hz, 13 dB/octave roll-off above 750 Hz, 6 dB/octave roll-off 350 to 225 Hz, flat 0.01 g^2/Hz 225 to 105 Hz, less than 10 seconds.
c. Transient vibration—at engine ignition and cut-off, staging, and separation.
d. Pyrotechnic shock—200 g terminal peak sawtooth, 0.7 to 1 ms duration during spacecraft V-Band separation.
e. Accoustic noise—143 dB overall, shaped spectra, less than 10 seconds.
f. Torsional vibration—69 Hz modulated sine wave pulse, 154 rad/sec^2, 0.14 second.
g. Static acceleration—nominal 5.6 g axially.

Free flight deep space (non-operating). —Vibration and shock will not be significant. The temperature is predicted to remain between 10° and 21°C.

Mars approach with entry of atmosphere and deceleration (operating). — The altimeter will be mounted behind the ablative heat shield. It will be subject to a rapid heat rise as the capsule is decelerated by the Martian atmosphere. There will also be about 14 watts dc of self heating due to operation. The maximum temperature will be a function of its thermal time constant and the net internal heat. It is estimated that the altimeter will not exceed 55°C during this period.

At a programmed altitude the altimeter will cause a parachute to be deployed. When the parachute opens, the ablative heat shield will separate and the altimeter will be lowered to a point well below the landing capsule. The altimeter will continue to perform its altitude measuring function until just prior to landing. In the extended position, a cooling thermal shock will be experienced.

Mechanical shocks will be experienced when the atmosphere is encountered, when the parachute is deployed, when the ablative heat shield is separated, and probably when the altimeter is lowered. The altimeter will have served its purpose before it impacts on Mars.

The rapid surface and internal heating followed by the thermal shock to surface cooling is the stress cycle most likely to cause reliability problems, if there are to be any.

Description of Design

General. —The radar altimeter which has evolved during the studies of Phases I and II is an electronically scanned radar. It uses an rf building block (RFBB) concept designated by the acronym MERA (Molecular Electronic for Radar Applications) and semiconductor integrated circuits (IC's) to achieve a truly solid-state radar.

Figure 1 is a functional block diagram of the altimeter. The 16 RFBB's are connected in a highly redundant parallel configuration but are individually phase controlled to provide the electronic scan in both x and y planes. Any two RFBB's may fail without excessive degradation of the radar's performance.

The IC's are complete functional circuits built into silicon semiconductor chips. Materials and technologies used have established reliability in both discrete parts and in other semiconductor networks. The semiconductor substrates, the epitaxial planar process, the vapor deposition of contact and conductor geometries and the compatible metal-to-metal bonding systems are known to be stable in the expected environment.

The MERA concept combines the IC technique with the thin film technique to produce an X-band, 9-GHz transmitter/receiver/duplexer. Stripline conductors, ground planes, and passive components are fabricated by thin film processes on ceramic material 0.7-inch square by 10 to 20 thousandths thick to which IC chips are attached. This produces an assembly with vibration resonant frequencies far above that which can be transmitted to them through the spacecraft structure. Thus, no vibration problems are expected within the RFBB's.

Theory of operation. —The theory of operation of the altimeter and of each block of Figure 1 is described in the following paragraphs.

Rf source: The rf source starts with a crystal controlled transmitter oscillator and a crystal controlled receiver local oscillator of 93.7500 and 88.5417 MHz respectively and with 20 mw output each. These operate continuously. A 4-dB buffer amplifier, power supply gated, follows each oscillator. A transmit-receive (TR) switch selects the proper signal from the buffer amplifiers. Following the TR switch, a 12.4-dB, power supply gated power amplifier feeds 700 mw to two broadband frequency multipliers, of 4X and 6X, with a combined loss of 10.4 dB. Thus, 64 mw of transmit or local oscillator signal, 2250 or 2125 MHz respectively, is delivered to the rf manifold.

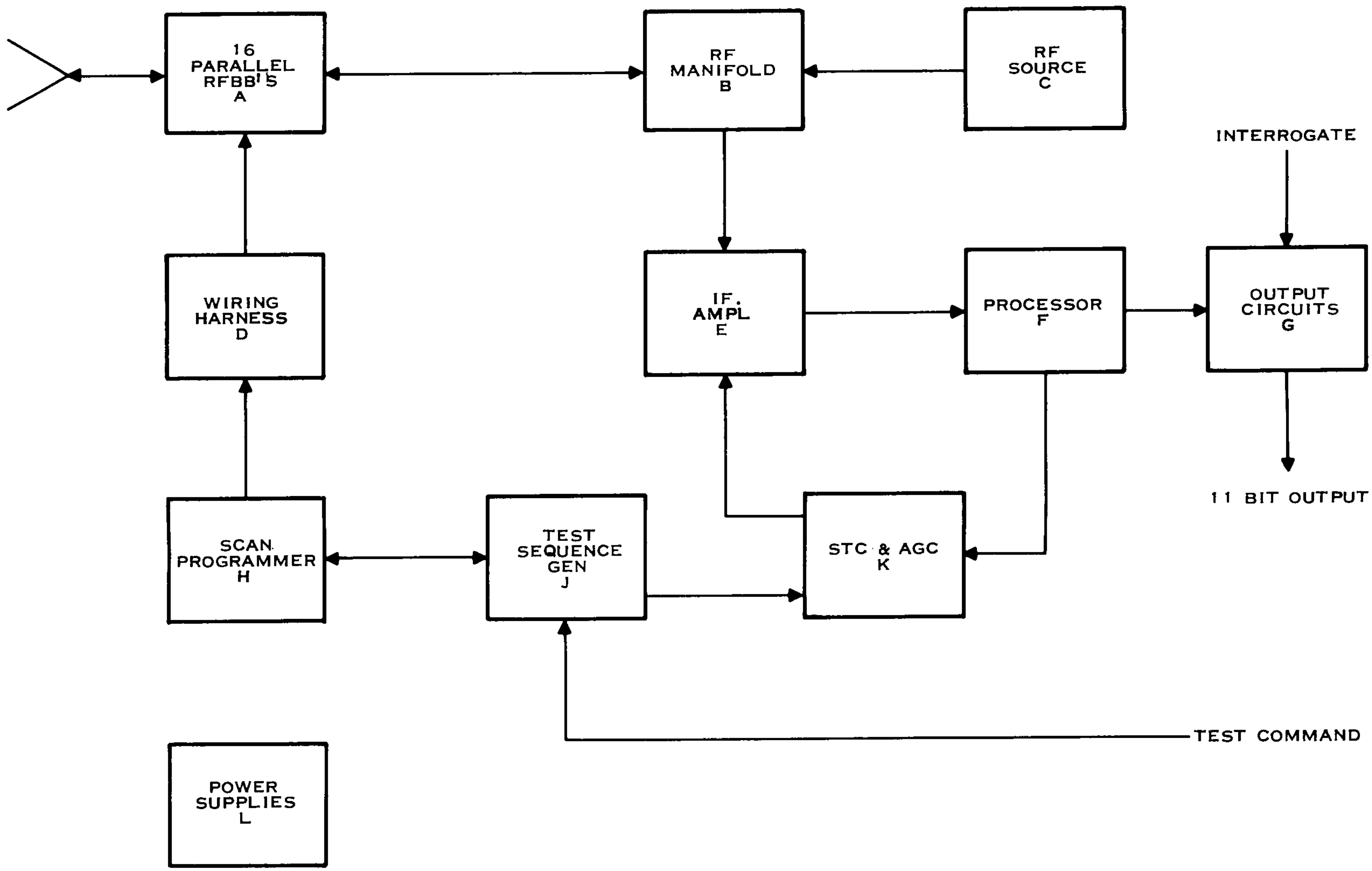


Figure 1. Space Probe Radar Altimeter Functional Block Diagram

Rf manifold: The signal selected by the TR switch in the rf source is distributed by 15 two-way stripline power dividers, which produce equal power distribution and phase shift, to the RFBB's. The 500-MHz if. signals from the RFBB's are vectorially combined in 5 four-way stripline power adders to produce a single if. output.

RFBB's: There are 16 RFBB's in a 4×4 matrix. These are individually phase controlled in both transmit and receive to produce an electronically scanned antenna pattern. The input from the manifold is amplified by a preamplifier. The preamplifier output is TR switched to either the transmit or local oscillator 4-bit digital diode phase shifter (line lengths selected by logic circuits). The output of the transmitter phase shifter is amplified to 2 watts [3 microseconds pulse at 2000 pulse rate frequency (PRF), 0.006 duty cycle]. Following the power amplifier is the 4X frequency multiplier and the antenna TR switch. The output of the receiver phase shifter is frequency multiplied by 4 and fed to the balanced mixer. The if. output of the balanced mixer is preamplified and fed to the rf manifold. Each RFBB has the necessary logic to control its phase shifters.

Scan programmer: To select the correct number of counter bits for each RFBB for each scan position (sector), a digital scan programmer is used. Four flip-flops connected as a ripple-through counter along with 16 four-input gates select the sector to be scanned. Each sector is "looked at" for four transmitted pulses so the logic is switched 500 times per second. Therefore, the clock frequency to the sector selector counter is 500 Hz, which is counted down from the 2-kHz PRF. The PRF is counted down from the 2-MHz input to the programmer.

A six-stage ripple counter is used for bit selection. The output stage disables the input clock through the stop gate. This counter counts 32 pulses, which is 360 degrees in both scan planes, and stops. This method was selected as the most economical to operate because of its low power dissipation and the most reliable because of its relative simplicity in design.

Processor: The radar receiver that has evolved contains a Type I (velocity sensitive) servo loop as a filter. This loop tracks the leading edge of the envelope of the received pulse. To maintain the fast response necessary, and also reduce the effective noise bandwidth of the system, a sampling circuit is employed. The if. input is envelope detected and video amplified. A coincident gate, operated by the received video pulse and a tracking pulse, triggers a sample and hold boxcar detector. The tracking pulse and boxcar trigger are time gates dependant on the output of a high speed comparator. The comparator output is triggered when the ramp voltage exceeds the output of an integrating amplifier. Since this amplifier amplifies only a change in the input, it is velocity sensitive or Type I. Therefore, any change in the time between the last received pulse and the pulse in the loop is detected and the loop reacts to track it.

If no signal is present, the signal recognition circuit senses the zero output of the circuit and activates a search generator that drives the integrating amplifier slowly from zero time to maximum time, or zero altitude to maximum altitude. Thus, the search generator is automatically activated whenever the received signal is "lost" outside the tracking loop.

Agc loop and sensitivity time control (STC): The altimeter accuracy depends on the received signal having a relatively constant amplitude over the altitude range. Therefore, a good agc circuit is required. A coincident gate, similar to that of the processor but longer to ensure peak detection, is used with a boxcar detector. A low pass amplifier makes the agc loop respond to average signal strength changes rather than pulse fading or sampling rates. The STC circuit increases the loop gain with altitude (time), thereby decreasing the required dynamic range of the agc loop.

Output circuitry: The output circuit is a simple gated counter with an accurate clock. The counter is preset to zero by the premaster trigger (PMT) and is started by the master trigger (MT), which is delayed 25 microseconds after PMT and also triggers the transmitter. It is stopped when the track gate is coincident with the received video pulse. Therefore, the number of counts represents time, or altitude, increments. A shift register receives the digital altitude data after each received pulse and holds it for read out at any time except during shift register updating.

Test sequence generator: At certain points in time during prelaunch checkout it is desirable to determine if each RFBB is still operating properly. A test sequence circuit, wherein each RFBB is used alone as a transmitter/receiver, is activated by a single wire command. This command gates on the test circuit which includes four flip-flops connected as a ripple-through counter and 16 four-input gates, which sequentially gate the RFBB's on. The transmitted rf can be monitored externally or a transponder can be used to check the complete system.

Power supplies: The primary power is 28 ±2 vdc. The altimeter is designed to use 5, 10, 30, −10, and −15 vdc. The power supply consists of a preregulator, a high frequency dc to dc converter, and a rectifier filter for each voltage. An additional circuit, which makes it possible to meet the low power allowance for the system, is the power programmer. This consists of three monostable multivibrators that control transistor switches used to gate power to circuits as they are needed.

Technical risk.—The RFBB is considered to be the only item of significant technical risk in the proposed altimeter. It consists of several subcircuits listed in Table 1. Among these, the significant circuit is considered to be the power amplifier, which must deliver approximately 2 watts peak of pulsed power at 2.25 GHz. The pulsewidth is 3 μs and the pulse rate frequency is 2000. Thus, the duty cycle is 0.006 and the average power

Table 1. —Reliability Analysis of Space Probe Radar Altimeter

Subassembly or Circuit	$F_R \times 10^{-6}$/hr
Microwave Manifold	1.80
RF Source	9.52
Scan Programmer	4.62
IF Amplifier	5.08
Processor	1.84
STC & AGC Loop	0.57
Output Circuits	2.94
Test Sequence Gen	4.75
Power Supplies	4.75
RFBB's, 16 in Parallel Redundant Circuit	≈ 0
Total Altimeter Failure Rate	35.87
Predicted MTBF	27800 hr

output per RFBB is 12 mw. However, 3 μs is considered to be sufficient time for thermal equilibrium in the transistor junction.

A reliability evaluation program will be initiated on the RFBB. This program will be directed primarily toward the power amplifier, but will include the complete subassembly. The thermal design of the power amplifier, the RFBB, and the RFBB matrixes will be given special consideration.

Current Reliability Analysis

Summary of reliability analysis. —The probability of successful operation of the altimeter is estimated to be 0.999982. This estimate is based on the assumption that all failures which may occur up to launch are detected before launch and that the probability of failure during launch and deep space flight are not significant. The high probability of success is to be achieved through the semiconductor integrated circuit type of RFBB's as transmitter/receivers in a highly redundant configuration and through the use of semiconductor integrated circuits in the logic and supporting circuitry. No thermal devices or mechanical components are to be included in the design.

Reliability block diagram. —A reliability block diagram was derived from the functional block diagram of Figure 1. It was determined from a failure modes and effects analysis that all of the circuits in blocks B through L are essential except for an insignificant part of block J, test sequence generator. Thus, for reliability estimation, these blocks are in series. Block A consists of 16 RFBB's in parallel, any two of which may fail without jeopardizing performance. It is shown by the equation in the following paragraph that this redundant configuration has a reliability of essentially unity. The block diagram is not presented graphically in this analysis.

Mathematical model. —The probability of success is given by the expression, $Ps = e^{-\lambda t}$, where λ is the failure rate of the equipment under consideration and t is the mission time. The probability of success of the redundant RFBB's of block A, Figure 1, can be expressed as

$$P_A = (P_{BB} + Q_{BB})^{16} .$$

This expression may be expanded into the following series:

$$P_A = P_{BB}{}^{16} + 16 P_{BB}{}^{15} Q_{BB} + \frac{16(15)}{2!} P_{BB}{}^{14} Q_{BB}{}^{2} + \ldots + Q_{BB}{}^{16} .$$

Under the assumption that zero, one or two failures are permissible, only the first three terms of the series are relevant. Using a failure rate, $\lambda_{BB} = 13.74 \times 10^{-6}$/hr, and a mission time, t = 0.5 hour, P_A was calculated to be 0.999999+. This is an equivalent failure rate for the parallel redundant configuration of block A, $\lambda_A \cong 0$.

The failure rate for the radar altimeter is given by the expression,

$$\lambda s = \lambda_A + \lambda_B + \ldots + \lambda_L .$$

This is summed in Table 1 to be 35.87×10^{-6}/hr, equivalent to an MTBF of 27800 hours. The probability of mission success is given by the expression, $Ps = e^{-\lambda st}$, where λs is the system failure rate and t is the assumed mission time of 0.5 hour. Ps is calculated to be 0.999982.

Reliability analysis. —Table 2 lists the circuits and assigned failure rates for an rf building block. Table 3 lists the circuits and assigned failure rates for the remainder of the radar altimeter. The failure rates assigned to the various parts are considered to be feasible rates considering the materials and fabrication techniques and the program schedule, that is, a working engineering model in 1969 with space qualified hardware throughout the 1971 to 1975 period.

Table 2. —Estimate of RFBB Failure Rate (Sheet 1 of 3)

Circuit Function	Part Complement	Type	Process or Material	No. Used (n)	F_R ($\times 10^{-6}$)	nF_R ($\times 10^{-6}$)
Preamplifier 2.25 or 2.125 GHz	Transistors	High Freq	Silicon (dev.)	2	0.05	0.10
	Resistors	Thin Film	Au, Al, MoAu	7	0.05	0.35
	Capacitors	Thin Film	Au, Al, MoAu, SiO_3	4	0.10	0.40
	Tuning Ckt	Thin Film	Au, Al, MoAu	3	NEGL	----
	Connections	Gold Ball Bonds		30*	0.001	0.03
Power Amplifier 2.25 GHz	Transistors	Power	Silicon (dev.)	5	1.00	5.00
	Tuning Ckt	Thin Film	Au, Al, MoAu	6	NEGL	----
	Capacitors	Thin Film	Au, Al, MoAu, SiO_3	1	0.10	0.10
	Connections	Gold Ball Bonds		20*	0.001	0.02
IF Amplifier 500 MHz	Transistors	L-146 Chip	Silicon (dev.)	3	0.05	0.15
	Capacitors	Thin Film	Au, Al, MoAu, SiO_3	7	0.10	0.70
	Resistors	Thin Film	Au, Al, MoAu	8	0.05	0.40
	Connections	Gold Ball Bonds		20*	0.001	0.02
Freq X4 Transmit	Varactor Diodes		Silicon Mesa	1	0.05	0.05
	Inductors	Thin Film	Au, Al, MoAu	10	NEGL	----
	Capacitors	Thin Film	Au, Al, MoAu, SiO_3	7	0.10	0.70
	Connections	Gold Ball Bonds		10*	0.001	0.01
Freq X4 Receiver L.O.	Varactor Diodes		Silicon Mesa	1	0.05	0.05
	Inductors	Thin Film	Au, Al, MoAu	10	NEGL	----
	Capacitors	Thin Film	Au, Al, MoAu, SiO_3	7	0.10	0.70
	Connections	Gold Ball Bonds		10*	0.001	0.01

*Estimated

Table 2. —Estimate of RFBB Failure Rate (Sheet 2 of 3)

Circuit Function	Part Complement	Type	Process or Material	No. Used (n)	F_R ($\times 10^{-6}$)	nF_R ($\times 10^{-6}$)
TR Switch to Antenna	Diodes		Silicon	2	0.01	0.02
	Capacitors	Thin Film	Au, Al, MoAu, SiO_3	4	0.10	0.40
	Inductors	Thin Film	Au, Al, MoAu	3	NEGL	----
	Resistors	Thin Film	Au, Al, MoAu	1	0.05	0.05
	Connections	Gold Ball Bonds		10*	0.001	0.01
TR Switch to Phase Shifters	Diodes		Silicon	2	0.01	0.02
	Capacitors	Thin Film	Au, Al, MoAu, SiO_3	4	0.10	0.40
	Inductors	Thin Film	Au, Al, MoAu	3	NEGL	----
	Resistors	Thin Film	Au, Al, MoAu	1	0.05	0.05
	Connections	Gold Ball Bonds		10*	0.001	0.01
Mixer, X-Band	Diodes	Mixers	Silicon, Schottky	2	0.05	0.10
	Capacitors	Thin Film	Au, Al, MoAu, SiO_3	1	0.10	0.10
	Inductors	Thin Film	Au, Al, MoAu	1	NEGL	----
	Connections	Gold Ball Bonds		10*	0.001	0.01
Phase Shifter Transmitter	Diodes		Silicon	8	0.01	0.08
	Inductors	Thin Film	Au, Al, MoAu	9	NEGL	----
	Capacitors	Thin Film	Au, Al, MoAu, SiO_3	17	0.10	1.70
	Connections	Gold Ball Bonds		10*	0.001	0.01
Phase Shifter Receiver L.O.	Diodes		Silicon	8	0.01	0.08
	Inductors	Thin Film	Au, Al, MoAu	9	NEGL	----
	Capacitors	Thin Film	Au, Al, MoAu, SiO_3	17	0.10	1.70
	Connections	Gold Ball Bonds		10*	0.001	0.01

*Estimated

Table 2. —Estimate of RFBB Failure Rate (Sheet 3 of 3)

Circuit Function	Part Complement	Type	Process or Material	No. Used (n)	F_R ($\times 10^{-6}$)	nF_R ($\times 10^{-6}$)
Logic	SCN	SN5400	Silicon Substrate	2	0.10	0.20
	SCN	SN7493	Silicon Substrate	1	0.10	0.10
	Connections	Gold Ball Bond		50*	0.001	0.05
Estimated Failure Rate for an RFBB						13.74

*Estimated

Table 3. —Estimate of Failure Rates of Other Circuits (Sheet 1 of 3)

Functional Name	Part or Name Type	Type Subdivision	Material Used	No. Used (n)	F_R ($\times 10^{-6}$)	nF_R ($\times 10^{-6}$/hr)
Microwave Manifold	Resistors	Thin Film	Au, Al, MoAu	35	0.05	1.75
	Circuitry	Thin Film	Au, Al, MoAu	--	NEGL	----
	Connections		Solder or Weld	50*	0.001	0.05
Subtotal						1.80
RF Source	Transistor	Power	Silicon (dev.)	1	1.00	1.00
	Transistor	High Freq	Silicon	4	0.05	0.20
	Diode	Switch	Silicon	2	0.10	0.20
	Varactor Diode		Silicon	2	0.05	0.10
	Resistor			14	0.01	0.14
	Capacitor		Mica	22	0.01	0.22
	Inductors	RF Choke	Molded Wire Wound	15	0.50	7.50
	Connections		Solder or Weld	120*	0.001	0.12
	Crystal	Quartz		2	0.02	0.04
Subtotal						9.52
Scan Programmer	SCN	Digital	Silicon Substrate	42	0.10	4.20
	Connections		Solder or Weld	500*	0.001	0.50
Subtotal						4.72
IF Amplifier Estimated to be 4X Preamp	Transistor	L-146 Chip	Silicon (dev.)	12	0.05	0.60
	Resistor	Thin Film	Au, Al, MoAu	32	0.05	1.60
	Capacitor	Thin Film	Au, Al, MoAu, SiO_3	28	0.10	2.80
	Connections		Solder or Weld	80*	0.001	0.08
Subtotal						5.08

*Estimated

Table 3. —Estimate of Failure Rates of Other Circuits (Sheet 2 of 3)

Functional Name	Part or Name Type	Type Subdivision	Material Used	No. Used (n)	F_R ($\times 10^{-6}$)	nF_R ($\times 10^{-6}$/hr)
Processor	SCN	Digital	Silicon Substrate	5	0.10	0.50
	SCN	Linear	Silicon Substrate	7	0.10	0.70
	Capacitor	Mica		4	0.01	0.04
	Connections		Solder or Weld	100*	0.001	0.10
	Capacitor	Tantalum		1	0.50	0.50
Subtotal						1.84
STC and AGC Loop	SCN	Digital	Silicon Substrate	1	0.10	0.10
	SCN	Linear	Silicon Substrate	4	0.10	0.40
	Capacitor	Mica		1	0.01	0.01
	Connections		Solder or Weld	60*	0.001	0.06
Subtotal						0.57
Output Circuits	SCN	Digital	Silicon Substrate	15	0.10	1.50
	Crystal	Quartz		1	0.02	0.02
	Transistor		Silicon	2	0.05	0.10
	Resistor	Carbon Film		6	0.01	0.06
	Capacitor	Mica		4	0.01	0.04
	Diodes	Switching	Silicon	2	0.01	0.02
	Inductor	RF Choke		2	0.50	1.00
	Connections		Solder or Weld	200*	0.001	0.20
Subtotal						2.94
Test Sequence Generator	SCN	Digital	Silicon Substrate	18	0.10	1.80
	Transistors	Switching	Silicon	48	0.05	2.40
	Resistors	Carbon Film		16	0.01	0.16
	Connections		Solder or Weld	380*	0.001	0.38
Subtotal						4.74

*Estimated

Table 3. —Estimate of Failure Rates of Other Circuits (Sheet 3 of 3)

Functional Name	Part or Name Type	Type Subdivision	Material Used	No. Used (n)	F_R ($\times 10^{-6}$)	nF_R ($\times 10^{-6}$/hr)
Power Supplies	Transistors	Power	Silicon	3	0.05	0.15
	Transistors	Switching	Silicon	15	0.05	0.75
	SCN	MSMV	Silicon Substrate	3	0.1	0.30
	Diodes	Rectifier	Silicon Substrate	10	0.01	0.10
	Capacitor	Ceramic		8	0.01	0.08
	Inductors	RF Choke		1	0.50	0.50
	Resistors	Carbon Film		11	0.01	0.10
	Transformer	DC-DC Conv		1	2.00	2.00
	Connections		Solder or Weld	160*	0.001	0.16
Subtotal						4.14

*Estimated

The failure rates for IC's, transistors, diodes, inductors, capacitors, and resistors represent interpretations of parts and equipment reliability histories. The failure rates for new MERA type, all solid-state microwave circuits represent extrapolations from similar IC's, thin film, and individual components with reliability histories.

Connection between vapor deposited contacts, on ceramic or silicon substrate, and other conductors can be made sufficiently reliable by using only compatible metal systems and avoiding the brittle intermetallic compounds such as the gold-aluminum which produces "purple plague". Alloying techniques will be given preference over gold wire thermo-compression bonding for making joints.

Connectors will not be used within the altimeter. Yet, any subassembly may be easily replaced by a technician competent in the use of a soldering iron. Connectors will be used in the interface between the altimeter and the spacecraft if specified by the procuring activity.

Growth potential. —The growth potentials of the radar altimeter are very significant. Increasing the mission to 48 hours of operating time is two orders of magnitude greater than the 0.5 hour considered in the present analysis. The failure rate of the RFBB array would remain insignificant regardless of size if the same level of redundancy were maintained. For an active mission time of 48 hours, it would surely be desirable to include redundancy in some or all of the supporting circuitry.

RELIABILITY AND QUALITY ASSURANCE PLAN FOR DESIGN AND DEVELOPMENT PHASE

Design Surveillance

During the design and development phase a reliability engineer will be assigned to the program. He will be located in the general area of the design personnel and thus will be aware of all problems and progress as the program proceeds. Texas Instruments feels that this approach is superior to the alternate approach wherein the reliability personnel are segregated from the designers and depend on data transmitted to and from the designers for reliability execution and control. The project oriented reliability engineer detects and corrects many small reliability problems on an informal basis. Some of these problems would not be detected by a remote reliability engineer. Others would be detected at a later date at which time additional cost and/or delays might be incurred. The program at Texas Instruments tends to be one of mutual understanding, respect, and cooperation in problem solving.

A central design data file will be maintained by the project design personnel in order to maintain a design history of the program. The reliability engineer will monitor this file. This file will include stress analysis, tolerance analysis, and failure mode and effects analysis.

Parts Program

The requirements of a spacecraft instrument place severe requirements on its parts complement. Some of these are:

a. Very low failure rate
b. Long expected life
c. Light weight
d. Low power consumption
e. Immunity to damage due to sterilization.

The radar design that has evolved during the study program is a "state-of-the-art" system. The parts complement for the altimeter will be selected in the following manner. A NASA approved parts list will be obtained. Hardware, basic materials, and electrical components of the altimeter that are standard will be selected from this list. Non-standard parts, such as RFBB's, MERA type microwave integrated circuits, and specialized IC's, both digital and linear, will be analyzed to determine their similarity to NASA approved parts in both function and fabrication techniques. A list of non-standard parts, the use of each, and a program outline for qualifying each part will be submitted to NASA for approval.

The non-standard parts will be composed of the following circuit elements.

a. Microwave circuits and other non-standard functions fabricated into silicon substrate. Confidence (if not qualification) may be obtained from similarity to standard components.
b. Thin film conductors, resistors, and capacitors may be fabricated in large sheets on ceramic and/or silicon and realibility tested to verify or determine the failure rate of each under controlled conditions.
c. Subassemblies (i.e., RFBB's consisting of thin film passive circuits and mounted chip active circuits) will be tested to evaluate the combination. It is thought that not enough of these will be available to qualify them on a statistical basis. However, step tests in temperature and voltage to destruction may reveal failure modes that are correctable. This should provide increased confidence in the design. Should the MERA RFBB's be applied to a

large array radar in a program parallel to the altimeter development, a statistically qualified failure rate of high confidence should evolve. Sterilization is covered in a separate document but will also be included in this plan.

Design Review Program

A formal program of planned, scheduled, and documented design reviews will be conducted at the system, subsystem, and major component level. These reviews will be comprehensive, critical audits of all pertinent aspects of the design, particularly its reliability. These reviews will be conducted at all major milestones in the program (to be scheduled during later revisions to this plan as set forth in the Program Management paragraph of the Introduction). Participation will be interdepartmental, including personnel from design, fabrication, reliability, quality, parts application and other appropriate support areas, as well as NASA representatives (at the discretion of the cognizant NASA installation). The cognizant reliability engineer and other review participants will sign all design review reports to indicate concurrence with the completeness of the review and the actions to be taken. The cognizant reliability engineer will also followup action items to ensure that the responsible groups have completed these actions satisfactorily. In connection with these reviews, Texas Instruments will submit the following:

a. A detailed description of the design review program including practices and procedures employed, a check list of design aspects to be covered, and schedule of individual reviews. See the outline in Appendix A. (Further details and a schedule will be provided in a later revision.)

b. Notification to the cognizant NASA installation or its designated representative, when so delegated, 15 days in advance of each review, including the system element to be reviewed, firm date, time, location and descriptive information on the review in question.

c. Design review reports, including a review representation list, a statement of actions to be taken and by whom will be provided to or be available for review by the cognizant NASA installation (at its discretion) within 21 days after the review meeting. However, necessary corrective action resulting from the review will be initiated and reported informally to the cognizant NASA installation within agreed time periods established at the review meeting.

The design review provisions herein will be invoked on all major subcontractors.

Each engineering design change, made for any reason after final design review of the element in question, will be submitted for review, analysis, and concurrence of the members of the design review group (or Change Control Board, if applicable). Where the nature of a change is considered by any member of the group to warrant a formal design review, such a review will be conducted prior to release of the change.

Maintainability and Elimination of Human-Induced Failures

Careful consideration will be given to the maintainability of the system and to the elimination of potential sources of human-induced failure throughout the entire contractual effort—from basic design through operational use. This will include the following:

a. A study of requirements for test, checkout, inspection, parts or components replacement disassembly and assembly, and self-monitoring, followed by provisions of access and other design features to enable performance of all checkout, repair and maintenance tasks.

b. An intensive effort directed toward making proper and safe use of the equipment convenient and unsafe use inconvenient or extremely difficult, thus enhancing the systems capability to be fabricated, handled, maintained, and operated with maximum ease and minimum hazard to life and equipment. This effort will cover the design of the equipment and all instructional material and training associated with its handling, storage, transportation, checkout, and use.

Texas Instruments realizes that an effective effort in these areas is an important means of enhancing reliability in the system. Features to eliminate potential human-induced failures and to enhance maintainability of the system will be given careful consideration in all design reviews.

Quality Assurance Functions

General. —Product quality is a major consideration in the design and development efforts at Texas Instruments. Programs are now in progress which are complying with NPC 200-2 and NPC 200-3. Thus the mechanisms and the personnel are currently available to support the development program of the radar altimeter.

Drawings and specification review. —Reviews of drawings, specifications, and technical documents will be performed to establish the characteristics that determine the quality and reliability of the system, and to provide criteria to judge performance to these characteristics. These reviews will be documented and such documentation will be made available to the NASA installation and its designated representative. The cognizant QA engineer will verify that drawings, specifications, and technical documents contain adequate requirements for determining and controlling the quality of all items, purchased or produced by Texas Instruments for the radar altimeter. Such requirements will be related to all phases of the system development including design, fabrication, testing, and end-use. In detailing quality requirements, all documents will include:

a. Identification of the article
b. Characteristics determined to influence quality
c. Inspection and test methods (including specific test equipment, environmental condition and sample size, as applicable)
d. Conformance limits.

Qualified and preferred parts: These reviews will include specific actions to maximize the use of parts and components that have been qualified as meeting the performance, reliability, and quality requirements of the contract. Feedback of information from previous experience with other space instruments developed at Texas Instruments will be used at this stage of the system development. The reviews will also include application of any preferred parts list cited in the contract or required to be established by Texas Instruments to:

a. Eliminate from the design parts known to be inadequate
b. Aid in planning parts and component testing and screening.

Government document review: Applicable government drawings, specifications, and technical documents will be reviewed as above for adequacy and necessary addenda and supplements will be provided to adequately define the quality requirements of the fabricated articles.

Planning: These reviews will be used for planning fabrication, tooling, measuring, and test equipments. In addition, they will be used for planning and inspection and test procedures.

Qualification test. —Qualification test of parts, components, subassemblies, and higher levels of assembly will be performed to demonstrate that the design is inherently capable of meeting the established requirements. The test will be designed to:

a. Locate significant failure modes
b. Determine the effects of varied stress levels

c. Determine the effects of combinations of tolerances and drift of design parameters
d. Determine the effects of combination and sequences of environments and of stress levels.

After a detailed review of the parts, components and subassemblies of the proposed altimeter, it is felt by Texas Instruments that only the RFBB may be considered a technical risk. It is felt that other parts may be qualified by similarity to NASA qualified parts as described in the Parts Program paragraph.

Material procurement and control. —Texas Instruments will assume the responsibility for the adequacy and quality of all purchased materials, articles, and services unless otherwise directed by the contracting agency in writing. This responsibility will include:

a. Selection of qualified procurement sources
b. Transmission of all design, reliability, and quality requirements to procurement contracts and purchase orders
c. Evaluation of the adequacy of procured articles
d. Effective provisions for early information feedback and correction of deficiencies
e. Providing technical assistance and training to suppliers when necessary to achieve desired reliability and quality levels.

Control of in-house fabricated articles. —Texas Instruments will maintain a program for quality control and necessary supporting documentation for all in-house fabricated articles to ensure that all contract, drawing, and specification requirements are obtained and maintained in the completed articles. The program and its application to all phases of fabrication will provide maximum assurance that the quality inherent in the design is maintained.

Nonconforming material. —Material review boards conforming to NPC 200-2 and NPC 200-3 currently exist at Texas Instruments.

Failure Reporting and Correction

Texas Instruments has a strictly controlled system for the reporting, analysis, correction, and data feedback of all failures and malfunctions that may occur throughout the fabrication, handling, test, checkout, and operation of the altimeter. Texas Instruments Standard Procedure, 18-8, Failure Analysis and Reporting, is included as Appendix D. On NASA and JPL programs, customer supplied forms are used.

Training and Certification of Personnel

Texas Instruments has personnel trained and certified to NASA and JPL requirements. These personnel will either be available to staff the altimeter program or will train additional personnel for this purpose.

RELIABILITY AND QUALITY ASSURANCE PROGRAM FOR PRODUCTION OF 10 UNITS

Training and Certification of Personnel

This will be an extension of the program instigated under the Training and Certification of Personnel paragraph.

Change Control

General. —Texas Instruments has a system which is NASA and/or JPL approved to ensure control of all documents affecting the quality program and for the incorporation of changes thereto. These documents include quality control procedures, engineering drawings, inspection and test procedures, specifications, procurement documents, engineering orders, processes, manufacturing and operating instructions, and similar documents. These documents are distributed to the proper points at the proper times in order that contract work and all quality program functions are accomplished in accordance with the latest applicable documents. The system also provides for the prompt removal of all obsolete documentation from operating areas. Quality and reliability program personnel review all changes to determine their effect upon the quality of the fabricated articles and upon the operation of the quality program. Special attention is given to changes involving interface relationships including those changes affecting articles not under Texas Instruments design control.

Effectivity. —The effectivity point is clearly defined for all changes except those which affect only presentation of information on a document (e.g. spelling or completeness) and do not affect materials, fabrication, or performance. Changes are made on the affected articles at an appropriate point, the changed articles are appropriately marked or identified, and applicable documents are revised accordingly. Provisions are made for adequate and timely inspection and test of all changed articles.

Failure Reporting and Correction

The program instituted under the Failure Reporting and Correction paragraph will continue in effect during production.

ENVIRONMENTAL TEST PROGRAM

The environmental test program is a joint task. The program manager is responsible to Texas Instruments management and to the customer for performance of the test. He will provide the test specimens and test equipment, direct the preparation of the test procedures, and provide technical assistance during the test. The cognizant QA engineer will verify that the test specimens and the test procedures conform to contract and specification requirements. Environmental test personnel will operate the environmental equipment and certify the environmental data. Acceptance test personnel will perform the test per the test procedure and certify the test data. The reliability engineer will review the test procedure, test data, and provide failure analysis and corrective action support as required. The customer will approve the test procedure and the test specimen and will provide a representative to witness the test. The program manager will direct preparation and submittal of the test reports for approval.

FLIGHT TEST PROGRAM

The flight test program will be performed in a manner similar to the environmental test, but project personnel, NASA personnel, or an outside agency will probably perform the test.

DOCUMENTATION

Documentation will be as specified in the contract or specification. It will be detailed herein during a later revision.

SCHEDULE AND RESPONSIBILITIES

A chart will be prepared, during a later revision, scheduling all tasks and assigning responsibility for their execution.

APPENDIX A

DESIGN REVIEW CHECK LIST (OUTLINE)

APPENDIX A

DESIGN REVIEW CHECK LIST
(OUTLINE)

1. MASTER CHECK LIST

   1.1 Functional Design

   1.2 Physical Design

   1.3 Human Engineering

   1.4 Test Results

   1.5 Logistics

2. FUNCTIONAL DESIGN

   2.1 Electrical and Electronic

   2.1.1 General

   2.1.2 Parts Selection and Application

   2.1.3 Preferred Circuits and Design Applications

   2.2 Mechanical Design Practices

3. PHYSICAL DESIGN PRACTICES

   3.1 Design Layout

   3.1.1 General

   3.1.2 Electrical and Electronic Layout

   3.1.3 Printed Circuit Layout

   3.1.4 Electromechanical

4.3 SAFETY FEATURES

4.3.1 Self Test

4.3.2 Fail Safe

APPENDIX B

ORGANIZATION

APPENDIX B

RELIABILITY ORGANIZATION

The Quality and Reliability Assurance (QRA) Department of the Apparatus Division of Texas Instruments is a staff organization which reports to the vice-president and division manager, through the division administration manager as shown in Figure B-1. This line of responsibility and authority, separated from the product department, ensures independence of action with management emphasis placed on all departments. The Quality and Reliability Assurance Department is organized in seven branches:

Reliability-Maintainability Engineering
Quality Assurance Engineering
Acceptance Testing
Environmental Laboratory
Inspection
Vendor Quality Control
Planning and Development.

The functions of the first four of these branches are described in the following pages.

Reliability-Maintainability Engineering Branch

The Reliability-Maintainability Engineering Branch is the organization which defines, plans, and directs the Apparatus Division reliability and maintainability program. This branch is responsible for technical support and direction of all reliability-maintainability activities in the division. This includes responsibility for initiation of policies and procedures; for the operation of a failure reporting, analysis, and corrective action system; for reliability-maintainability education and training; and for the development of reliability-maintainability information, techniques, and skills. In addition, the branch provides specialists and direct support to projects as required to meet project reliability-maintainability objectives. The branch is functionally organized in four groups. The specific responsibilities of each of the groups are as follows.

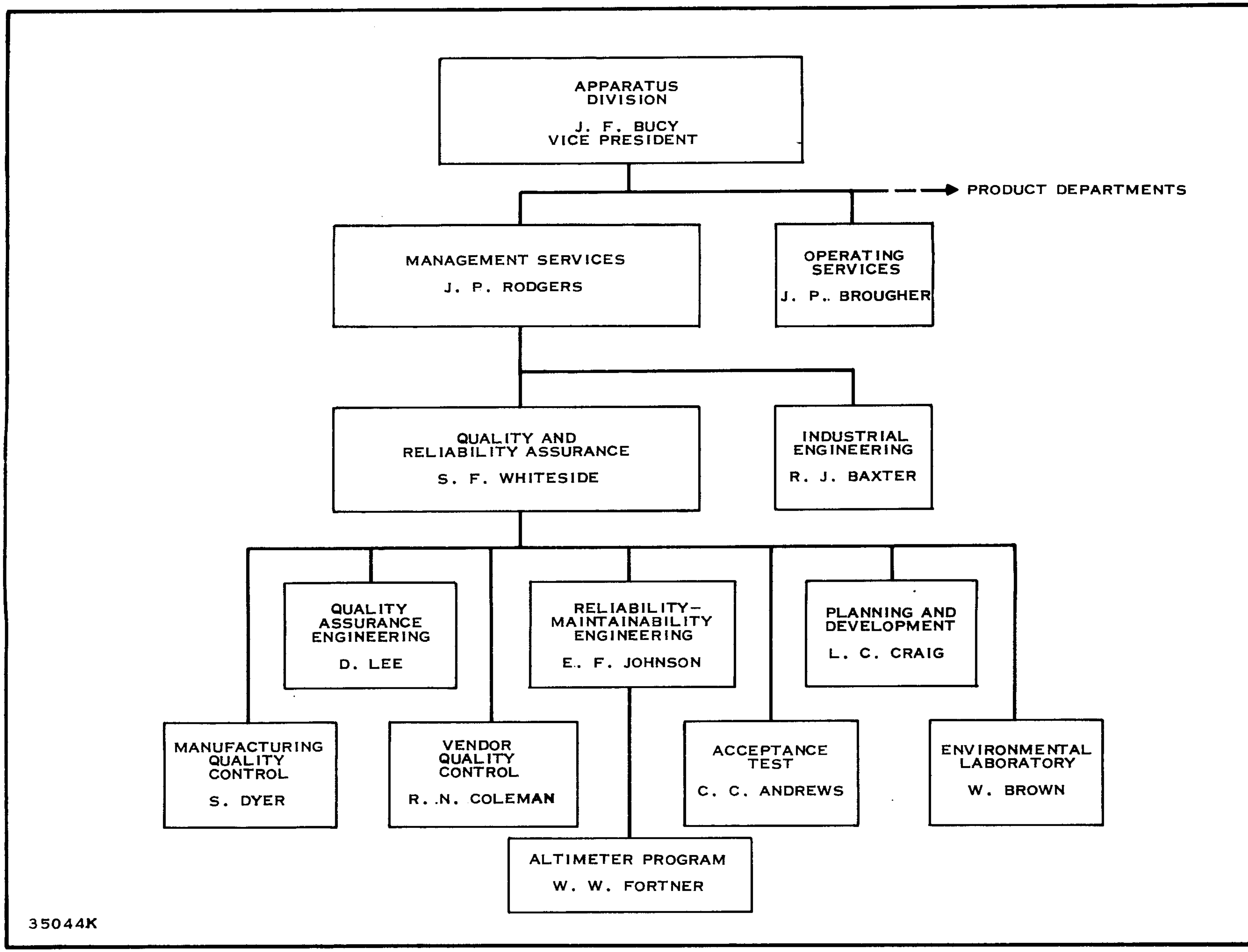


Figure B-1. Quality and Reliability Assurance Engineering Department Organization

Systems reliability. —The project reliability engineer is the technical specialist assigned to a project who is fundamentally responsible for defining, planning, and executing a reliability program that meets the requirements of military and/or customer specifications. He is thoroughly skilled in reliability engineering techniques including reliability models, prediction, allocation, circuit stress analysis, tolerance analysis, failure effects analysis, redundancy, accelerated and safety-factor testing, part and system qualification procedures, and reliability demonstration methods.

After analyzing system reliability specifications and equipment performance requirements, the reliability engineer will devise a program plan which will achieve the desired reliability goals. The plan will list a number of tasks which must be accomplished to satisfy project reliability prediction, stress analysis, tradeoff studies, design review, etc. The completed reliability plan, and any subsequent changes, must be approved by the project engineer, the reliability engineering branch manager, and, usually, by the customer.

The reliability engineer monitors the performance of his program tasks and works to resolve any problems which may arise. His normal channel of authority is through the project engineer or by delegation of the project engineer. Any disagreement which cannot be resolved by the project engineer and the reliability engineer will be referred to higher authority in their respective departments. The reliability engineer will keep the project engineer informed as to progress, problems, and any other matters related to the reliability program and the success of the project. He will represent the project to the customer in all matters pertaining to reliability. He will establish liaison with the customer's reliability representatives and will assume the task of satisfying their requests and of keeping them informed in documented reliability reports.

Systems maintainability. —The project maintainability engineer is the technical specialist (assigned to a project) who is fundamentally responsible for defining, planning, and executing a maintainability program plan that meets the requirements of military and/or customer specifications. He ensures that maintainability principles in general and those specified by the customer, in particular, are incorporated into the design. He performs the maintainability analysis of the equipments and specifies or determines the qualitative and quantitative requirements of the system or subsystem.

Reliability-Maintainability Studies Group. —The Reliability-Maintainability Studies Group is responsible for gathering and disseminating information throughout the division regarding reliability/maintainability techniques and project reliability experiences. This group manages the division failure reporting system and maintains a central file of failure data and statistics. The division standards laboratory is also under the supervision of this group.

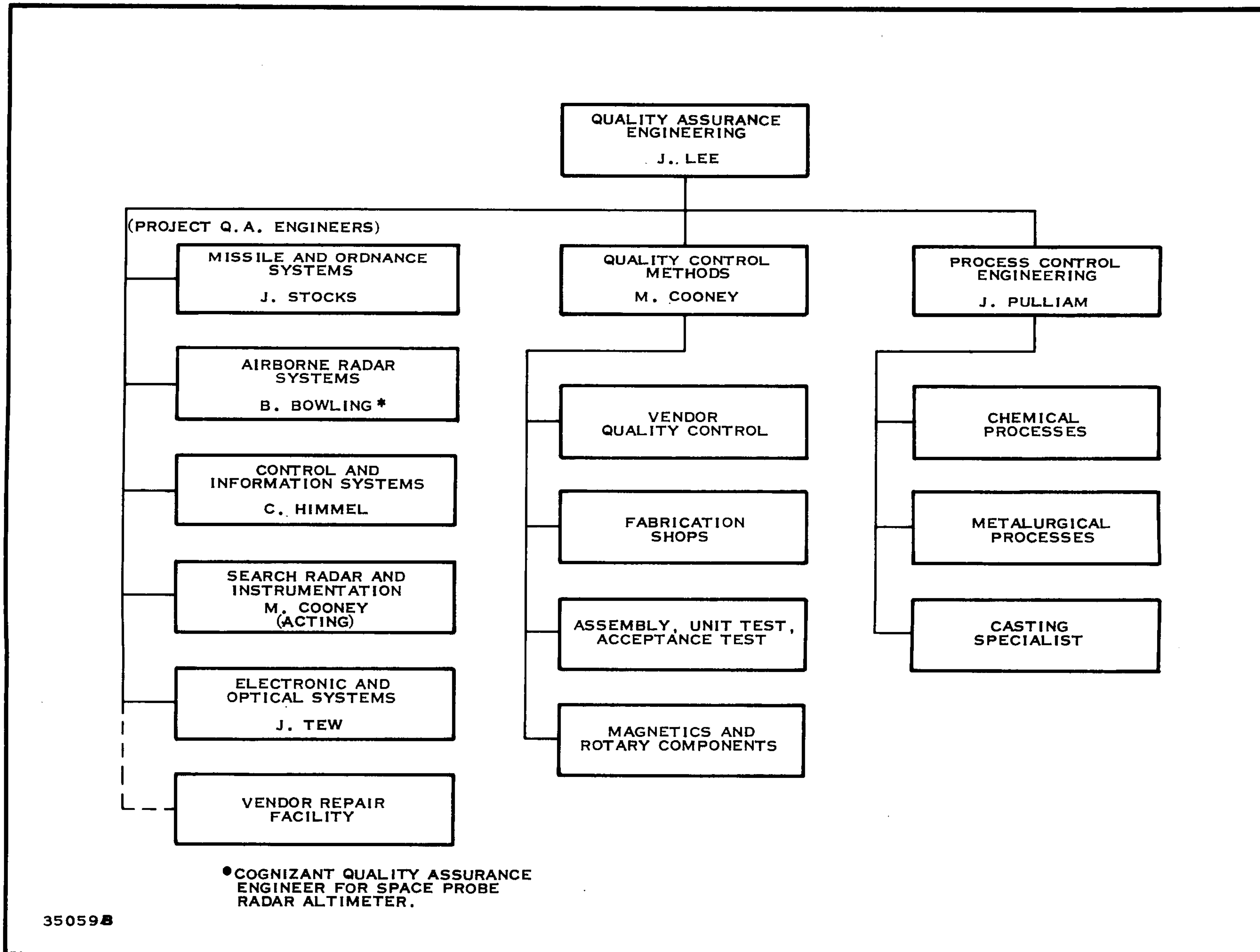


Figure B-2. Quality Assurance Engineering Branch Operation

Parts and Materials Group. —This group provides information and services to projects concerned with component parts and materials. It is composed of the following sections.

Parts engineering: Component parts specialists in this group provide a central source for parts reliability data, preferred parts list, parts qualification, procurement and screening specifications, application criteria, and failure analysis assistance.

Standards: An engineering function responsible for the establishment of standardization practices for parts and materials used in Apparatus equipment. These efforts are directed to select, and urge the use of, standard parts taking into consideration their cost, delivery, and quality history.

Failure Analysis Laboratory/Parts and Materials Qualification and Evaluation Laboratory: The Failure Analysis Laboratory is equipped for testing, examining, and analyzing failed parts. Precision tools for probing, cutting, and microsectioning small parts are provided. Photographic documentation is afforded with a Polaroid industrial camera and microscope. The Parts and Materials Qualification and Evaluation Laboratory's function is to assist the parts engineers in the evaluation of parts and materials to be used by the Apparatus Division.

Quality Assurance Engineering Branch

Quality Assurance Engineering Branch (shown in Figure B-2) is responsible for technical support to the entire department, as well as to project engineering and manufacturing functions as required. A division-level staff activity, this branch is responsible for determining customer quality requirements for each project as derived from a purchase order or other contractual specification. The Quality Assurance Engineering Branch implements these requirements into a quality assurance plan through inspection instructions; test planning and methods; and quality consultation with project representatives, customer and supplier representatives, and inspection and test personnel. The effectiveness of the quality assurance plan is also monitored by the cognizant quality assurance engineer, who is responsible for its performance in guaranteeing the customer's satisfaction.

Manufacturing Quality Control Branch. —The Manufacturing Quality Control Branch is responsible for all inspection of partially completed subcontracted items, fabrication and assembly in-process and acceptance inspection, and packing inspection. Also, the responsibilities of this branch include tooling inspection, gage inspection and control, and materials review and disposition of manufactured products.

Acceptance Test Branch. —The Acceptance Test Branch performs or witnesses functional acceptance testing of a product, including units, equipments, and complete systems, and also maintains the quality assurance functional test file. Functional testing includes detailed individual, sample, and life tests specified by the project engineer to ensure conformance to all applicable drawings and specifications. The functional test file, in addition to acceptance test data, also includes reliability history data on each unit.

Environmental Laboratory. —The Environmental Laboratory, a branch-level operation, equips and maintains Apparatus Division environmental test facilities. It is responsible for the planning and performance of all environmental testing to ensure that products conform to all applicable environmental specifications.

APPENDIX C

PREDICTED EFFECTS OF STERILIZATION FOR THE DESIGN, DEVELOPMENT AND PRODUCTION OF A SPACE PROBE ALTIMETER

APPENDIX C

PREDICTED EFFECTS OF STERILIZATION FOR THE DESIGN, DEVELOPMENT AND PRODUCTION OF A SPACE PROBE ALTIMETER

SUMMARY

Standard parts will be selected from customer supplied parts list. Nonstandard parts and custom designed parts will use materials and processes which produce a sterilizable part. No reliability problems are anticipated due to the sterilization requirement.

INTRODUCTION

Texas Instruments Incorporated has been engaged by the National Aeronautics and Space Administration, Langley Research Center (NASA, LRC) to perform a study to define the design of a space probe altimeter. This analysis has been prepared in response to Paragraph 4. 2. 2 of Statement-of-Work for Study to Define the Design of a Space Probe Altimeter L-6050, dated 19 August 1965, and prepared by Langley Research Center, Langley Station, Hampton, Virginia.

The analysis discusses the temperature limitation and the susceptibility to chemical damage by ethylene oxide (ETO) of each part or material proposed in the radar altimeter.

CONCLUSIONS

It is predicted that the radar altimeter will not incur damage because of subjection to sterilization, as specified in JPL Specification VOL-50503-ETS, dated 12 January 1966. However, it will be necessary to take extreme care in selecting materials, or protective coatings, which are resistant to oxidation by ETO.

ANALYSIS OF PARTS AND MATERIALS COMPLEMENT

The sterilization requirements are specified in JPL Specification VOL-50503-ETS, dated January 1966 and titled:

a. Environmental Specification Voyager Capsule Flight
b. Equipment Type Approval and Flight Acceptance Test
c. Procedures for the Heat Sterilization and Ethylene Oxide Decontamination Environments.

The susceptibility of parts and materials to each of the two environments will be discussed separately.

Heat Sterilization

It is a known fact that high temperatures tend to weed out weak or defective electronic parts. Such temperature stresses are used in parts conditioning or screening. However, parts defects may range from minute to major defects. Therefore, it is not likely that all defects will be removed during screening. There is a small probability that some parts will fail during thermal sterilization. The design problem is to keep this probability of failure at a negligibly low level.

The maximum temperature specified above is 135°C. Most components, semiconductors in particular, are processed at higher temperatures during the normal manufacturing operations.

A major effort at JPL has been concerned with heat sterilization. Many types of parts, selected from the JPL preferred parts list, have been evaluated in the thermal sterilization environment.

The insulation resistance of certain test specimen groups of capacitors, of solid tantalum dielectric, showed a decrease by a factor of 10 as a result of sterilization. These generally recovered during 100 hours of subsequent life test at rated DC voltage and temperature. But during this recovery period, several catastrophic failures occurred in one of the test groups, whose insulation resistance was affected by sterilization; whereas, the first catastrophic failures of the test groups unaffected by sterilization occurred after 4000 hours. It is understood that a retest of solid tantalum capacitors is being made by JPL.

Chemical Sterilization

Chemical sterilization makes use of ethylene oxide (ETO) gas. The composition of the decontaminating agent is specified to contain 12 percent ETO and 88 percent dichlorodifluromethane (Freon 12 or Genetron 12) by weight. It is understood that a program of significant proportions is to be initiated by JPL to study the effects of ETO on electronic parts. The results of this program will be followed closely.

PLANNED RELIABILITY PROGRAM ACTIVITIES

Standard parts and materials will be selected from NASA or JPL preferred parts and materials list. The capability of these parts and materials to withstand the sterilization environment will be verified.

The RF building block will be the major nonstandard part. The sterilization environment is considered a major parameter during its present evolution and will continue to be so through the altimeter program.

Other nonstandard parts will be identical to standard parts relative to materials and processes. The capability of these parts to withstand the sterilization environment will also be verified.

Sterilization will be considered in all design reviews. JPL and other programs pertaining to sterilization will be monitored.

Table C-1. Tabulation of Possible Compatibility with Parts and Materials Complement (135°C is Indicated), Sterilization Environment

	Parts and Materials	Maximum Storage Temperature °C	ETO Tolerant
1.	Integrated Monolithic Circuits, standard parts, hermetically sealed	150	yes
2.	Silicon Transistors and Diodes, hermetically sealed	175–200	yes
3.	Silicon Monolithic or discrete component chips mounted on silicon or ceramic substrate with thin-film passive components and circuitry, hermetically sealed	175	yes
4.	Resistor, fixed, carbon film, Texas Instruments type CG, hermetically sealed	175	yes
5.	Resistor, fixed, metal film, IRC types CCM, CCA, CCB	165	yes
6.	Resistors, fixed, carbon composition ABC types, CB, EB, GB	150	yes
7.	Resistor, fixed, wirewound DA1 type AGS	275	yes
8.	Resistor, variable, wirewound Bourns type 224	175	yes
9.	Resistor, variable, carbon composition, Bourns type 3051	150	yes
10.	Capacitor, fixed, tantalum, Sprague 350D	150*	yes
11.	Capacitor, fixed, tantalum, Sprague MIL style CL 14 and CL 16	175	yes
12.	Capacitor, fixed, mica, Elemnco type DM	150	yes
13.	Solders and Bonding Material (to be selected)	> 150	yes
14.	Quartz frequency control crystals	175	yes
15.	Teflon or Silicon	> 200	yes
16.	Glass base printed circuit boards	> 150	yes

*Leakage current will be increased but Sprague states that it will return to normal after the temperature is reduced and rated voltages are applied.

Table C-1. Tabulation of Possible Compatibility with Parts and Materials Complement (135°C is Indicated), Sterilization Environment (Continued)

	Parts and Materials	Maximum Storage Temperature °C	ETO Tolerant
17.	Silicon potting material	> 200	yes
18.	Copper and copper alloys	> 200	no
19.	Silver and silver alloys	> 200	no
20.	Magnesium and magnesium alloys	> 200	no
21.	Mercury and mercury alloys	> 200	no
22.	Iron or steel containing rust	> 200	no
23.	Anhydrous chlorides of iron, tin, aluminum	—	no

APPENDIX D

TEXAS INSTRUMENTS FAILURE ANALYSIS AND REPORTING PROCEDURE

1. PURPOSE

To define the method for reporting on failures, and the analyses of parts, assemblies, and systems that do not perform to specifications.

2. ORGANIZATIONAL UNITS AFFECTED

Apparatus - Dallas

3. SCOPE

This procedure will be followed on all production contracts in which "hardware" is delivered to a customer. However, development projects may participate in this program if desired or if specified by contract.

Exceptions to this procedure must be made in writing to the manager of the Quality and Reliability Assurance department.

4. GENERAL

Analysis of parts, assemblies, and systems failing to meet performance specifications is essential in order to continuously produce reliable products. This procedure enables engineering, manufacturing, and quality assurance departments to recognize the effect their activities have on product reliability and the method for taking corrective action on items that fail.

5. REPORTING FAILURES

5.1 Quality Assurance Report

The Quality Assurance Report (QAR), TI-3907, attachment A, is initiated for assemblies or systems that fail during acceptance or operational testing.

The QAR is completed by the person discovering that an equipment has failed; this includes persons from Quality Assurance Test, the cognizant project, or any responsible and knowledgeable witness to the trouble.

The QAR form states the symptoms and conditions of failure, the diagnosis, and a description of repair, replacement, or adjustment necessary to make the equipment ready for retesting. Details for completing the form are shown in attachment A.

5.2 Failure Report

The Failure Report, TI-3908, attachment B, is initiated by the Failure Analysis Laboratory.

The completed form states the condition of the part, apparent cause of failure, and any pertinent comments that may be of value to the responsible project.

Details for completing the form are shown in attachment B.

5.3 Assembly & Test Parts Hold Envelope

The Assembly & Test Parts Hold Envelope, TI-3909, attachment C, identifies and protects parts replaced in assembly and test areas. On large parts the envelope is attached to the part.

The form is originated by the person replacing the part, in accordance with instructions shown in attachment C.

NOTE: Repairable assemblies and fabricated parts are normally "tagged" with an Inspection Hold Tag, TI-5548, and are not included in the failure analysis program.

6. ROUTING OF DOCUMENTS AND PARTS

Routing of Quality Assurance Reports and parts from Quality Assurance Test through the Failure Analysis Laboratory and the project is shown in attachment D.

Routing of Assembly & Test Parts Hold Envelopes from the manufacturing area through the Failure Analysis Laboratory and the material review area is shown in attachment E.

Special routings of documents may be approved by the manager of Reliability Engineering to analyze failures occurring in other areas, such as engineering laboratories, field installations, and incoming inspection.

7. RESPONSIBILITIES

7.1 Quality Assurance Test

Quality Assurance Test is responsible for initiating Quality Assurance Reports when an assembly fails to meet specifications during acceptance testing. Retesting of the repaired assembly will not begin until the repaired assembly, the completed QAR, and the replaced parts, when applicable, are returned to Quality Assurance Test.

Follow-up copies of QAR's and the parts, will be placed at a QAR collection point (to be determined by the Manager of Quality Assurance Test) on the same day that the failed assembly is retested.

Quality Assurance Test will forward a Subassembly Record (originated by Systems Test for each equipment) to Reliability Studies for each assembly or system delivered. The record will show the delivery date, serial number, manufacturing sequence number, assembly nomenclature, acceptance test hours, and a compilation of QAR numbers issued against each assembly listed on the record.

7.2 Failure Analysis Laboratory

7.2.1 Processing Quality Assurance Reports

The Failure Analysis Laboratory is responsible for collecting daily, the processed QAR's from Quality Assurance Test.

All QAR's, with parts attached, will be analyzed within 48 hours after receipt and forwarded to the responsible project, with a completed Failure Report. The Project is notified if special testing is required and a longer time period is necessary.

Quality Assurance Reports, with no parts attached, are forwarded to the responsible project immediately by the laboratory.

7.2.2 Processing Rejected Parts From Assembly Areas

The Failure Analysis Laboratory will receive all rejected parts daily from the assembly areas. (Parts not routinely delivered to the Failure Analysis Laboratory include frames, castings, chassis, reflectors, cathode-ray tubes, and magnetrons.)

Each part delivered to the laboratory will be in or attached to a completed hold envelope, TI-3909. Parts will be delivered to the failure laboratory by Dispatching and will be sorted by project.

The laboratory will select parts for examination according to:

1. Where the part was rejected. Only those from manufacturing test are normally examined.

2. Whether or not the parts came from a participating project.

3. The type of rejection. Parts obviously damaged in handling are not examined.

4. Whether or not the identification of the part is sufficient to make a worthwhile appraisal of the trouble.

Parts received from the assembly areas and examined will be forwarded to the material review area within 72 hours. Projects are notified if special testing is required and a longer time period is necessary. Parts not selected for analysis are sent to the material review area daily.

Failure Reports are completed on parts examined and routed as defined in attachments B and E.

Monthly, the laboratory will summarize findings on parts examined and submit a report to the participating projects and the manager of Reliability Engineering.

7.3 Reliability Studies

Periodically, Reliability Studies will collect Subassembly Records, QAR's, and Failure Reports, and prepare a reliability record on each item delivered to the customer.

Chargeable failures will be determined and verified with the responsible project. Also, a record of observed mean-time-between-failures (MTBF) on parts will be kept by Reliability Studies; the records will be made available to the responsible projects.

Reliability Studies will review the 'corrective action' portion of each completed Failure Report and will forward pertinent information to the Failure Analysis Laboratory.

7.4 Participating Projects

The participating projects will process copies of the QAR and Failure Report as follows:

(1) Failed Part Involved - Project will first complete 'corrective action' portion of Failure Report, retain white copies of both QAR and Failure Report and send the canary copy of Failure Report to Reliability Studies. Pink copy of QAR is destroyed.

(2) Failed Part Not Involved - Project receives white copy of QAR from Failure Analysis Laboratory, which indicates that repair is complete. Pink copy of QAR is destroyed.

The project engineer participating in the failure analysis and reporting program is responsible for:

1. Instructing project members in the operation of the program.

2. Completing and forwarding failure report forms as described in this procedure.

3. Providing reliability studies with an up-to-date parts list for every assembly involved in the program.

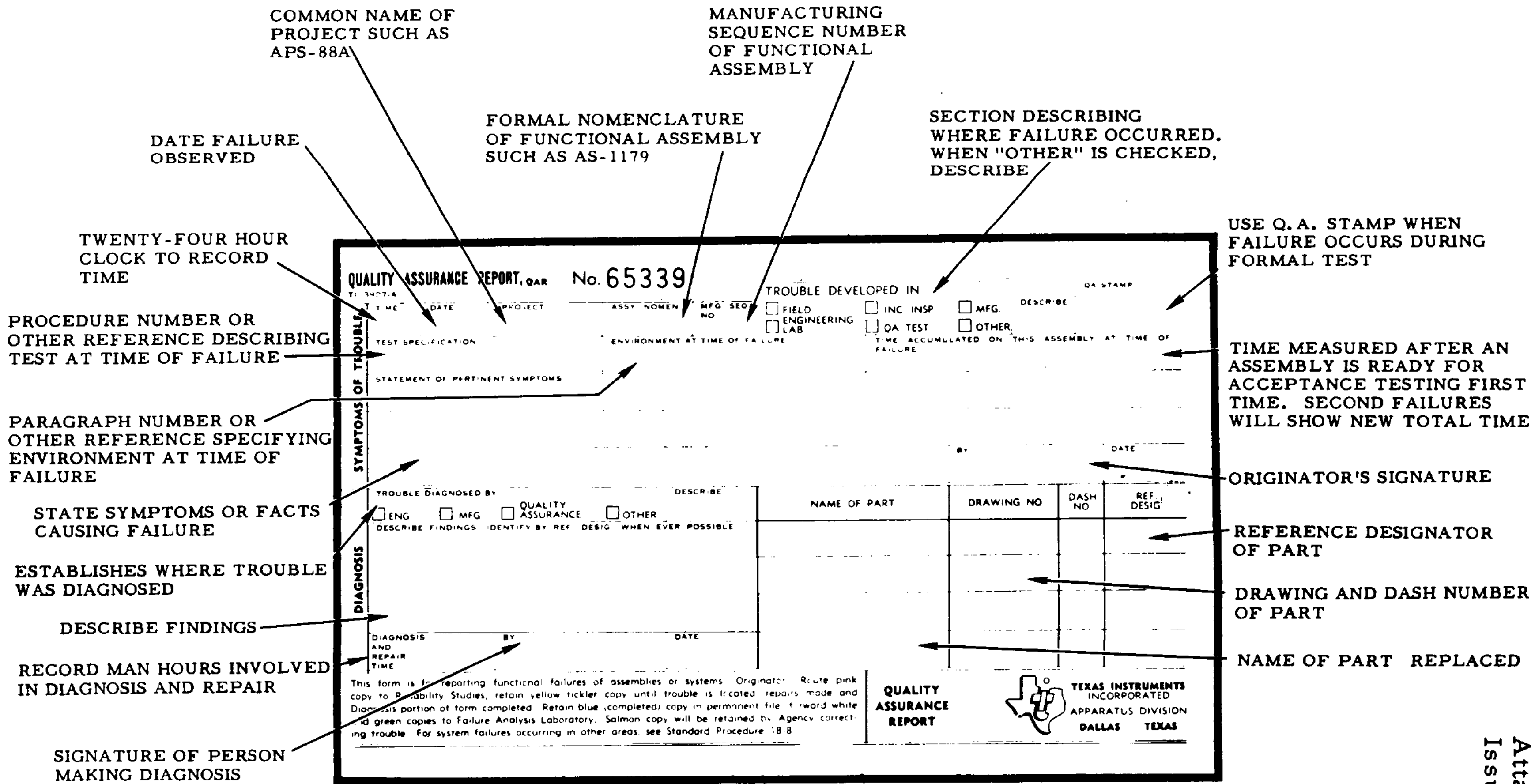
8. REPORTING ON MAINTAINABILITY

When required by contract, Quality Assurance Test will initiate an Equipment Maintenance Report (EMR) TI-6486, for each Quality Assurance Report issued on assemblies or systems that fail during acceptance or operational testing to assist the maintainability engineer in determining a mean-time-to-repair on TI products.

Detailed instructions on completing the form are shown in attachment F.

J. Fred Bucy

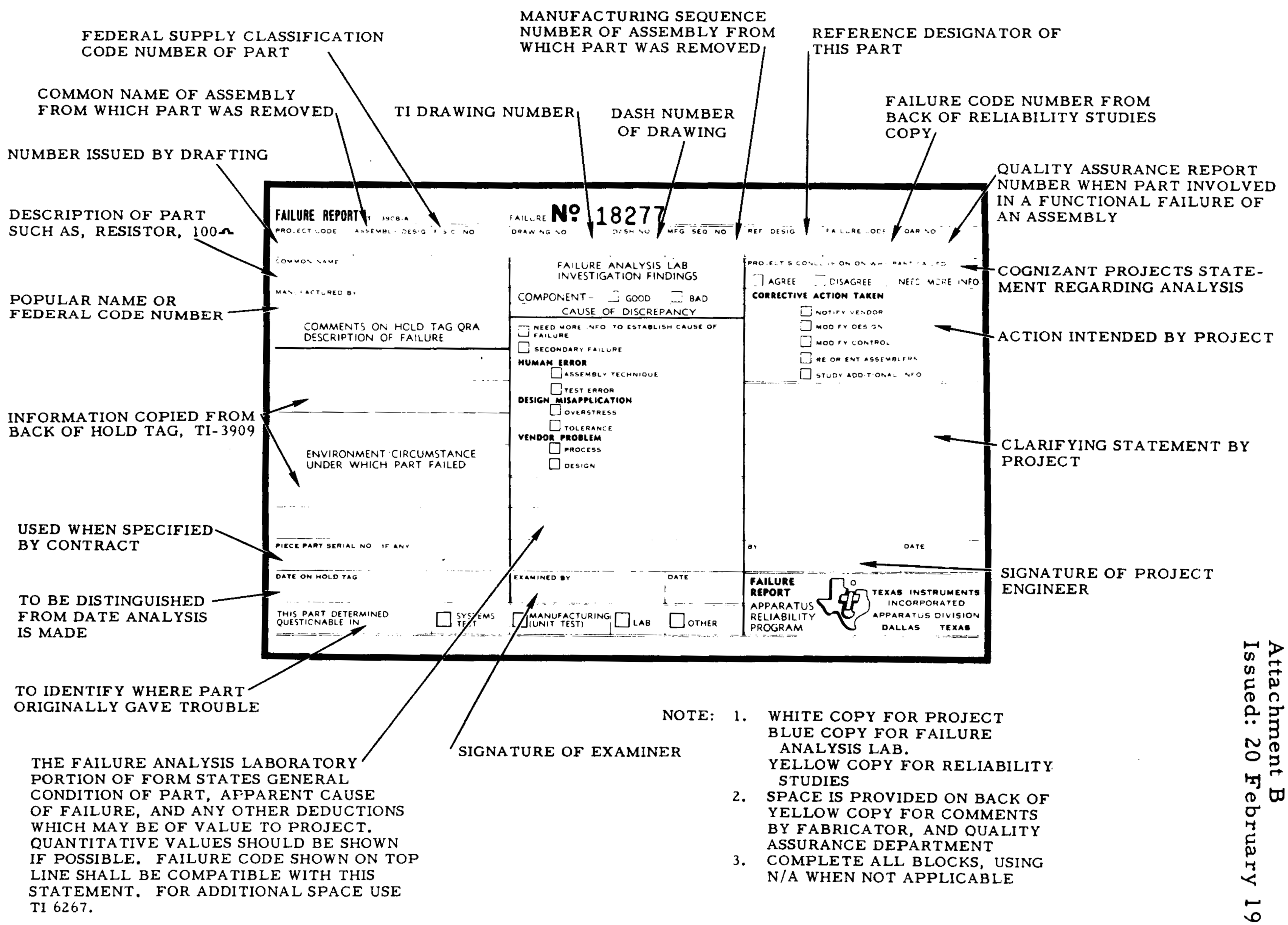
J. FRED BUCY
Vice President



NOTE: COMPLETE ALL BLOCKS, ~~USING~~ N/A WHEN ~~NOT~~ APPLICABLE

6 COPIES OF QAR TO:

PINK:	ALERT PROJECT AND RELIABILITY ENGINEERING IMMEDIATELY OF A FAILURE
WHITE:	PROJECT AS A PERMANENT RECORD
YELLOW:	QAR ORIGINATOR
BLUE:	QUALITY ASSURANCE TEST RECORDS
SALMON:	MANUFACTURING (UT)
GREEN:	RELIABILITY STUDIES



NOTE:
1. WHITE COPY FOR PROJECT
   BLUE COPY FOR FAILURE ANALYSIS LAB.
   YELLOW COPY FOR RELIABILITY STUDIES
2. SPACE IS PROVIDED ON BACK OF YELLOW COPY FOR COMMENTS BY FABRICATOR, AND QUALITY ASSURANCE DEPARTMENT
3. COMPLETE ALL BLOCKS, USING N/A WHEN NOT APPLICABLE

ASSEMBLY & TEST PARTS
HOLD TAG
TEXAS INSTRUMENTS INCORPORATED
APPARATUS DIVISION

QA TEST REPORT NO. . . ______ — QUALITY ASSURANCE TEST REPORT NUMBER WHEN PART ENCLOSED HAS BEEN REPLACED TO CORRECT MALFUNCTIONING OF EQUIPMENT

NAME OF PART . . . . ______ — COMMON NAME OF PART REPLACED

TI PART NO. . . . . . ______ — DRAWING & DASH NUMBER

REFERENCE DESIGNATOR . ______ — ESTABLISHES LOCATION OF PART IN CIRCUIT

ASSEMBLY DESIGNATION . ______ — FORMAL NOMENCLATURE OF ASSEMBLY PRODUCING PART SUCH AS - AS-1492

MFG. SEQUENCE NO. . . ______ — SEQUENCE NUMBER OF NOMENCLATURED ASSEMBLY

PROJECT IDENTIFICATION . ______ — COMMON NAME OF PROJECT SUCH AS APS-88A

REJECT LOCATION . . . ______ — ACTIVITY DECLARING PART A REJECT - SUCH AS U.T.

REJ ON WO or EO . . . ______ — WORK OR ENGINEERING ORDER ASSIGNED TO PROJECT

DATE [ ] ORIGINATOR ______ — NAME OF PERSON REPLACING PART

*QTY [ ] OK TO RSR NEW PART [ ] NEW PART RSR WRITTEN BY [ ]

FAILURE ANALYSIS RESULTS:

OK [ ] FAILURE CODE [ ]

DISPOSITION: SCRAP [ ] REWORK [ ]

RETURN TO VENDOR [ ] USE AS IS [ ]

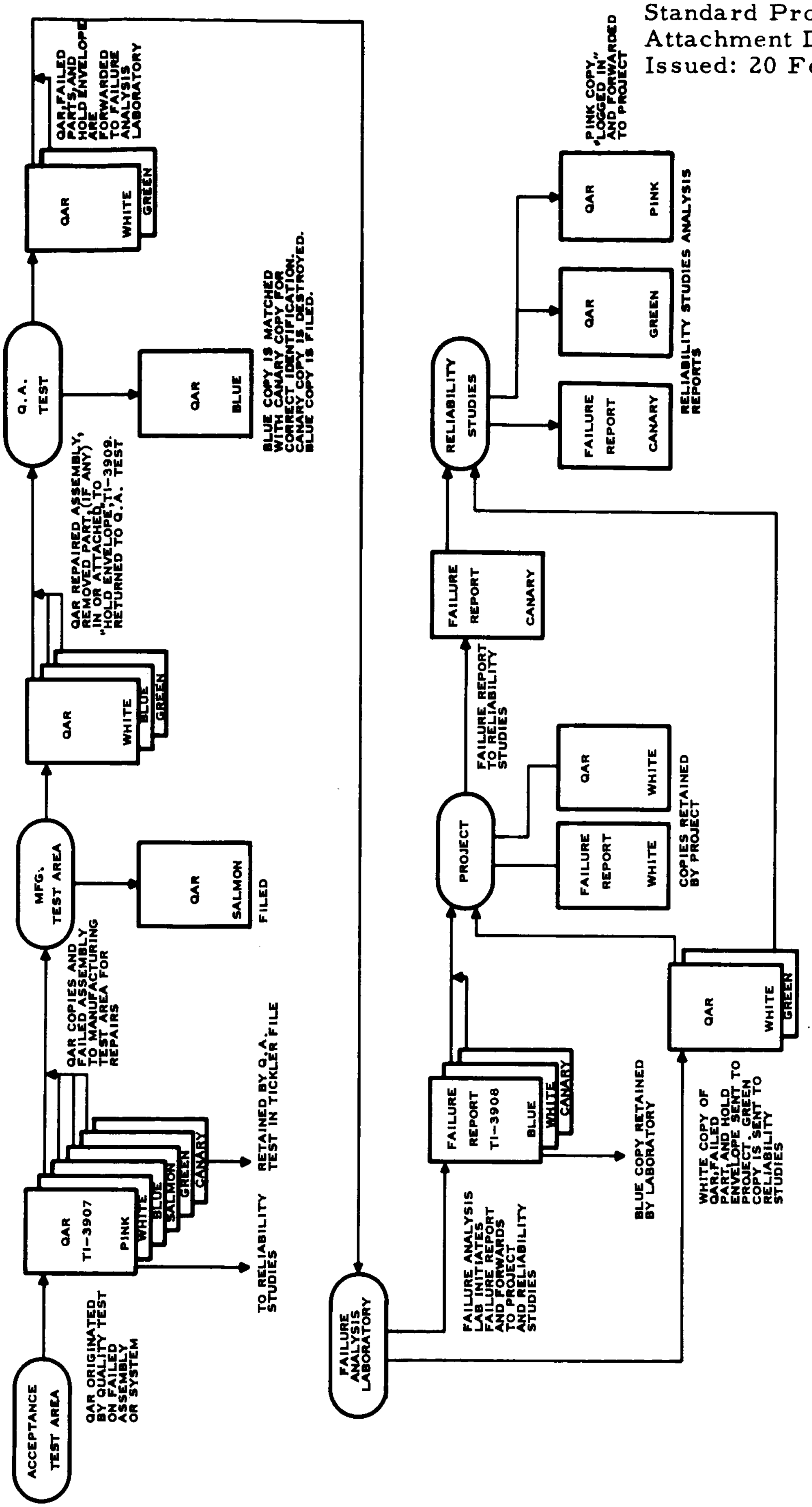
APPROVALS		
	MFG. ENG.	DATE
	PROJ. ENG.	DATE
	QA ENG.	DATE
	OTHER	DATE

INSTRUCTIONS

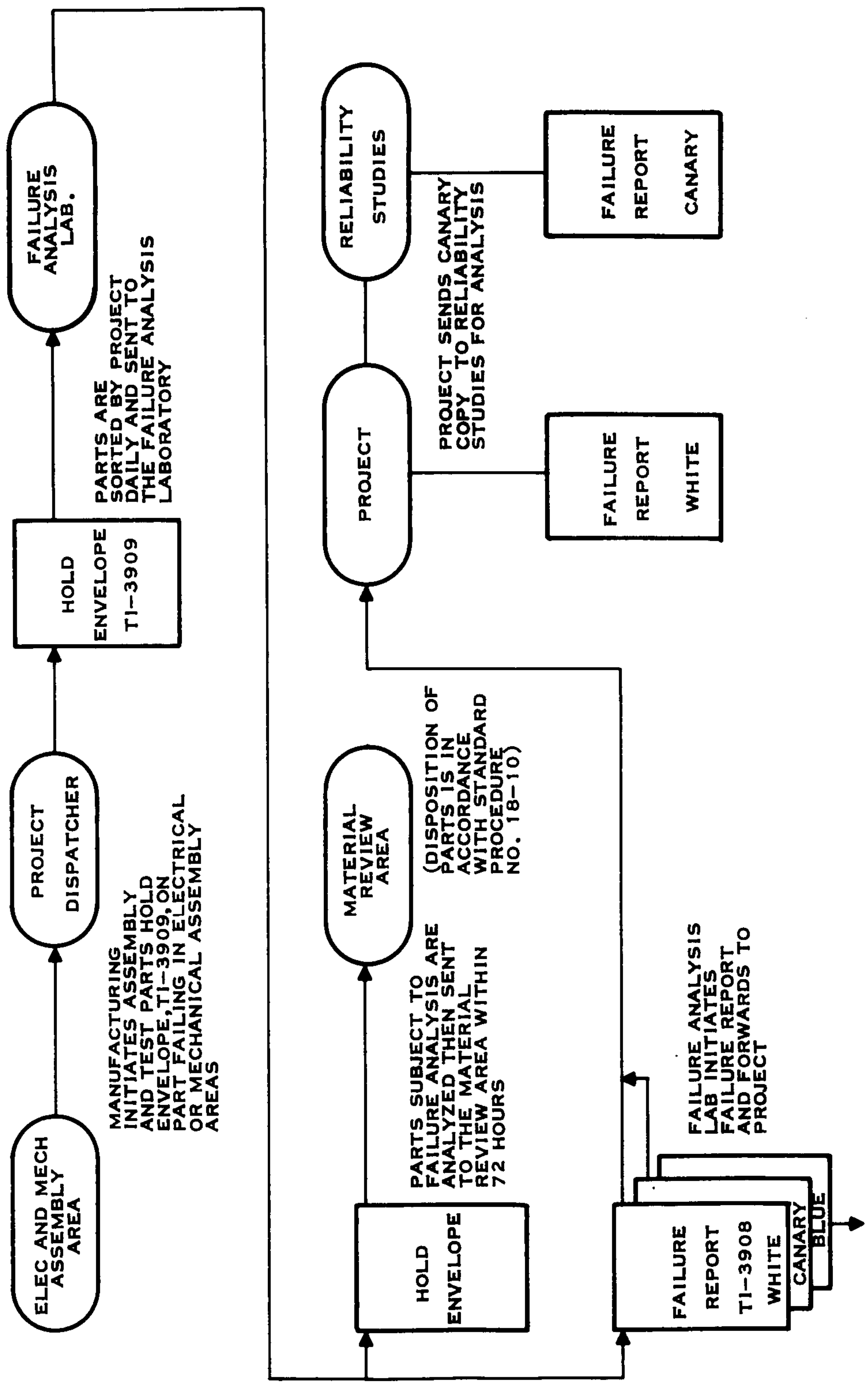
1. Complete all blocks in first section, use NA for "Not Applicable."
2. *Use one tag for each part except when identical from same reference designator in same assembly.
3. Describe symptoms or discrepancy on reverse side of tag.

NOTE: REMAINDER OF FORM USED FOR MATERIAL CONTROL PURPOSES

TI-3909



ROUTING OF QUALITY ASSURANCE REPORTS AND FAILURE REPORTS INITIATED FROM ACCEPTANCE TEST AREAS



ROUTING OF REJECTED PARTS FROM ELECTRICAL AND MECHANICAL ASSEMBLY AREAS

EQUIPMENT MAINTENANCE REPORT (EMR)

QAR NUMBER (1)	PROJECT (2)	ASSEMBLY (3)	SERIAL OR TAG NO (4)

STEPS IN MAINTENANCE OF EQUIPMENT	ACTIVITY INVOLVED (A)	NO. OF MEN REQ. (17)	TIME (18) HRS.	TIME (18) MIN.	CLOCK NUMBER (19)	DATE (20)	COMMENTS (16)
(5) VERIFICATION OF DISCREPANCY REPORTED ON QAR							
(6) ISOLATING TROUBLE AREA TO ☐ BOX ☐ SUB ASSY ☐ PART							
(7) GAINING ACCESS TO AREA INDICATED ABOVE							
(8) ADJUSTMENT, AND/OR							
(9) REPAIR, AND/OR							
(10) REMOVAL OF ITEM							
(11) REPLACEMENT OF ITEM							
(12) RE-ASSEMBLY							
(13) RE TEST BY MAINTENANCE ACTIVITY							
(14) RE-TEST BY Q.A. TEST							
(15) OTHER STEP. DESCRIBE:							

(A) Typical Activities involved:-Eng. (Engineering Labs); U. T. (Manufacturing); S.T. (Q.A. Test); E.A. (Electrical Assy.); M. A. (Mechanical Assembly)
(B) Data to be entered only for applicable steps.
(C) White Copy to project. Blue Copy to Q.A. Test. Salmon Copy to Manufacturing, and Cherry Card Copy to Reliability Studies.

EQUIPMENT MAINTENANCE REPORT TI-6486

TEXAS INSTRUMENTS INCORPORATED
APPARATUS DIVISION
DALLAS TEXAS

GENERAL INSTRUCTIONS:

Emr's are used to collect information on the maintainability of our products. Normally, they will be initiated by quality assurance test, and will always be related to a quality assurance report (QAR) describing a functional failure occurring during acceptance test. This form will follow the general route of QAR's as outlined in Std Proc. 18-8.

DETAILED INSTRUCTIONS FOR FILLING OUT FORM:

1. QAR number: Record number from QAR form, TI-3907.
2. Project: Use common name, such as, APS-88A.
3. Assembly: The formal nomenclature of functional unit, such as, RT-497B.
4. Ser. or Tag No.: Serial or Mfg. Seq. number of assembly recorded in box (3)
5. Verification of defect reported on QAR: Time taken by maintenance activity to verify symptoms reported.
6. Isolating trouble area: Time required to determine general cause of symptom, check appropriate block to show area involved.
7. Gaining access to defect: Time required to expose trouble so that corrective action can be taken in the form of repair, replacemen adjustment.
8. Adjustment, and/or: Time taken to align, calibrate, balance, or the like.
9. Repair, and/or: Time to rework, such as resoldering.
10. Removal of item: Time to remove item regardless of whether it is subsequently reused, replaced, repaired, or adjusted.
11. Replacement of item: Time to replace regardless of whether it is new or has been used.
12. Re-assembly: Time to return assembly to a condition suitable for re-test.
13. Re-test by maintenance activity. Time involved in verifying that assembly is functioning properly after repair, replacement or adj'mt.
14. Re-test by Q.A. test: Time involved in verifying that assembly is no longer demonstrating those symptoms that originally caused QAR to be issued subsequent acceptance test failures for same symptoms will be cause for initiating new QAR & EMR.
15. Other step, Describe: List other steps as necessary.
16. Comments on maintainability of item involved: Statement can be made by any knowledgable person, and approved by supervisor of maintenance activity or project manager.
17. Number of men required: Maximum number of men required at any one time during this step.
18. Time: Show hours and/or minutes.
19. Clock number: Clock number of person responsible for completing step. Inspection stamp may be used.
20. Date: Month - day - year.

BIBLIOGRAPHY

The entries herein constitute a Reliability Bibliography which was found to be of some value in the Space Probe Altimeter Study.

Asterisk (*) marked entries were considered of special value.

STERILIZATION

Barney, W., "Cleanliness is Next to Mars," Electronics, Vol. 38, 13 Dec 1965, p. 134-140

*Lockyear, W.H., "Parts Sterlization at the Jet Propulsion Lab," Evaluation Engineering, Vol. 5, Sep/Oct 1966, p. 34

Magistrate, V.J., "Engineering Problems in Capsule Sterilization," Astronautics & Aeronautics, Vol. 4, Feb 1966, pp. 80-84

Sagan, C. and Coleman, S., "Spacecraft Sterlization Standards and Contamination of Mars," Astronautics & Aeronautics, Vol. 3, May 1965, pp. 22-27

Watkins, H.D., "Severe Voyager Sterilization Criteria Set," Aviation Week and Space Technology, Vol. 83, 6 Dec 1965, p. 58

"Keeping It Clean," Electronics, Vol. 38, 29 Nov 1965, p. 34

*"Immaculate Voyager Will Visit Mars; Spacecraft Sterilization," Machine Design, Vol. 38, 3 Mar 1966, pp. 106-111

RELIABILITY

Adams, J. and Workman, W., "Semiconductor Network Reliability Assessment," Proceedings of the IEEE, Vol. 52, No. 12, Dec 1964, pp. 1624-1635

Alelyunas, P., "Reliability," Space/Aeronautics, Vol. 42, Oct 1964, pp. 48-55

Baker, S.C., "Building Reliability into Space Instruments," Electronic Industries, Vol. 22, Oct 1963, pp. 98-101, 107

Ducan, D.B., "Reliability Trends in Space Electronics," Electronic Industries, Vol. 22, Jun 1963, pp. I-2—I-4

Gilmore, H., "Method of Reliability Estimates and Demonstration Data Presentation," Industrial Quality Control, Vol. 21, Apr 1965, pp. 505-508

Golovin, N.E., "Reliability Engineering and Success in Space Exploration," Industrial Quality Control, Vol. 22, Mar 1966, pp. 457-464

Hovda, Robert E. and West, W.J., "Controlling Stress Increases Reliability," Electronic Industries, Vol. 22, Jun 1963, pp. I-5—I-9

Kasper, D.L. and Dallimore, G.R., "Two Step Potting Ups Reliability of Welded Modules," Space/Aeronautics, Vol. 39, Mar 1963, pp. 144-145

Lawson, P., "Reliability of Redundant Integrated Circuits in Failure Dependent Application," Proceedings of the IEEE, Vol. 53, May 1965, p. 505

McGinnis, F., "Space Age Accuracy and Reliability," ISA Journal, Vol. 12, Jan 1965, pp. 55-56

Morris, O.G., "Apollo Reliability Analysis," Astronautics & Aeronautics, Vol. 3, Apr 1965, pp. 52-55

Wuerffel, H.L. and Dunply, R.P., "Relay Communications Satellite; A Study in the Achievement of High Reliability," Industrial Quality Control, Vol. 22, Jan 1966, pp. 355-363

"'Results Versus Needs' Themes; SAE-ASME-AIAA Reliability Conference," The SAE Journal, Vol. 72, Sep 1964, pp. 100-103

"Cold Welding is Confirmed as Real Hazard in Space," Machine Design, Vol. 37, 16 Sep 1965, p. 15

"Gemini-6," Product Engineering, Vol. 36, 6 Dec 1965, p. 48

*"Status Report of Integrated Circuits Reliability," Microelectronics and Reliability, Vol. 4, No. 4, Dec 1965, pp. 315-330

SPACE ENVIRONMENTS

Bouquet, F.L. Jr., "Radiation Hazards of Space," Space/Aeronautics, Vol. 39, May 1963, pp. 72-77

Burrill, E.A., "Simulating Space Radiation," Space/Aeronautics, Vol. 41, May 1964, pp. 78-87

Donaldson, E.E.; Braun, E.A.; and Muscari, J.A., "Vacuum as an Environment and Insulator," IEEE Transaction on Parts, Materials, and Packaging, Vol. PMP-1, No. 3, Dec 1965

Honaker, W.C. and Bryant, F.R., "Radiation Effects on Transistors for Space," Nucleonics, Vol. 21, Jul 1963, p. 56

Jones, E.W., "Design Guide-Lines for Space Thermal Environments," Electronic Industries, Vol. 24, Apr 1965, pp. 82-84

*Klass, Philip J., "Space Vacuum Raises Avionic Problems," Aviation Week and Space Technology, Vol. 76, No. 4, 22 Jan 1962, pp. 75-76

*Wagner, W.A. and others, "Effect of Space Environment on Materials," Nucleonics, Vol. 22, Aug 1964, pp. 114-119

"Hazards are About as Predicted; Mariner IV During the First Half of its Flight," Machine Design, Vol. 37, 13 May 1965, p. 22

ELECTRONICS AND DESIGN

Drew, L.C., "Using Microcircuits in High-Resolution Range Counters," Electronics, Vol. 36, 22 Nov 1963, pp. 31-33

Husson, C., "Bringing Microelectronics to Spacecraft," Astronautics & Aeronautics, Vol. 2, Apr 1964, pp. 29-33

Kelley, A.J., "NASA's New Electronics Research Center," Astronautics & Aeronautics, Vol. 3, May 1965, pp. 58-67

Kelley, A.J., "Research for Space Enters the Electronics Age," Electronics, Vol. 38, 19 Apr 1965, pp. 117-119

Lampell, A.A., "Off-the-Shelf Integrated Circuits for Versatile and Accurate Timer," Electronics, Vol. 38, 13 Dec 1965, pp. 70-73

Mason, J.F. and Wolff, M.F., "Missile & Space Electronics; Special Report," Electronics, Vol. 34, 17 Nov 1961, pp. 87-118

*Olesen, H.H.L., "Designing Against Space Radiation," Electronics, Vol. 37, 28 Dec 1964, pp. 61-71; Vol. 38, 11 Jan 1965, pp. 70-76

Whitaker, A.B. and Schuhlein, C., "Integrating Spacecraft Electronics," Space/Aeronautics, Vol. 42, Aug 1964, pp. 53-59

"Space Electronics: New Components Needed," Electronics, Vol. 38, 11 Jan 1965, pp. 91-92

REPORTS

*Jet Propulsion Laboratory, Environmental Specification, Mariner C. Flight Equipment, Type Approval Environmental Test Procedures, Assembly Level, JPL Spec. 30250B

Jet Propulsion Laboratory, Preferred Parts List, Reliable Electronic Components, JPL Spec. ZPP-2061-PPL-G

*Jet Propulsion Laboratory, Reliability Considerations in the Design, Assembly, and Testing of the Mariner IV Power System, JPL Report No. 32-729

McDonnell Aircraft Corporation, Extraterrestrial Environments from 60 000 Feet to Lunar Orbit, McDonnell Aircraft Report No. En-296 Serial No. 38

*Environmental Engineering, Handbook of Instructions for Aerospace Systems Design, Vol. V, HIASD 1st ed. AFSCM 80-9

*Avco, Voyager Design Studies, Vol. 3, System Analysis, Avco RAD-TR-63-64, 15 Oct 1963

*Space Materials Handbook, 2nd ed., 1st Suppl., NASA SP-3025, ML-TDR-64-40

REPORTS BY TEXAS INSTRUMENTS INCORPORATED

Hanson, Gary, Permanent Damage Effects of Neutron Radiation on Selected Silicon Transistors, Report No. 03-65-05

*Worst-Case Analysis Report for Mariner C. Encoder, Report No. 11-76110-11

Semiconductor Integrated Circuits Bulletin SC-8000

Reliability Reports, 1962, 1963, 1964; Bulletins SC-3952-863, SC-5556-664, SC-7378-265

Integrated Circuits Seminar 1965 Report

*Molecular Electronics for Radar Applications, Final Report Phase I, 1st and 2nd Interim Report Phase II, Texas Instruments Report No. 03-65-116, 03-66-16, 03-66-30